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Optimization of the Performance of a Solar Concentrator System with a Cavity Receiver Using the Genetic Algorithm

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Abstract : The use of solar energy as a sustainable renewable energy source has gained significant attention in recent years. Solar concentrating systems (CSP), which direct solar radiation onto a receiver, are an effective means of producing high-temperature thermal energy. Cavity receivers, known for their high thermal efficiency and reduced heat losses, are particularly noteworthy in these systems. Optimizing their design can enhance energy efficiency and reduce costs. This study leverages the genetic algorithm, a powerful optimization tool inspired by natural evolution, to optimize the performance of a solar concentrator system with a cavity receiver, aiming for a more efficient and cost-effective design. In this study, a system consisting of a solar concentrator and a cavity receiver was analyzed. The concentrator was designed as a parabolic dish, and the receiver had a cylindrical cavity with a helical structure. The primary parameters were defined as the cavity diameter (D), the receiver height (h), and the helical pipe diameter (d). Initially, the system was optimized to achieve the maximum heat flux, and the optimal parameter values along with the maximum heat flux were obtained. Subsequently, a multi-objective optimization approach was applied, aiming to maximize the heat flux while minimizing the system construction cost. The optimization process was conducted using the genetic algorithm implemented in MATLAB with precise execution. The results of this study revealed that the optimal dimensions of the receiver, including the cavity diameter (D), receiver height (h), and helical pipe diameter (d), were determined to be 0.142 m, 0.1385 m, and 0.011 m, respectively. This optimization resulted in improvements of 3% in the cavity diameter, 8% in the height, and 5% in the helical pipe diameter. Furthermore, the results indicated that the primary focus of this research was the accurate thermal modeling of the solar collection system. The simulations and the obtained results demonstrated that the optimization applied to this system maximized its thermal performance and elevated its energy efficiency to a desirable level. Moreover, this study successfully modeled and controlled effective temperature variations at different angles of solar irradiation, highlighting significant improvements in system efficiency. The significance of this research lies in leveraging solar energy as one of the prominent renewable energy sources, playing a key role in replacing fossil fuels. Considering the environmental and economic challenges associated with the excessive use of fossil resources—such as increased greenhouse gas emissions, environmental degradation, and the depletion of fossil energy reserves—developing technologies related to renewable energy has become a vital priority. Among these, solar concentrating systems, capable of achieving high temperatures, are particularly important for industrial and heating applications. This research aims to optimize the performance of such systems through precise design and simulation, making a significant contribution to the advancement of advanced technologies and the efficient utilization of solar energy in Iran, thereby addressing the country's future energy needs effectively.

Keywords : cavity receiver, genetic algorithm, optimization, solar concentrator system performance
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